RELIABILITY ANALYSIS

AND

CORRECTIVE ACTION SUMMARY

FOR THE

SATURN V HYDRODYNAMIC SUPPORT EQUIPMENT

ER 14038

NOVEMBER 1965

MARTIN MARIETTA CORPORATION
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FOREWORD

This Reliability Analysis and Corrective Action Summary Report has been prepared under Contract NAS 8-11903, Exhibit A, paragraph III-V, Reliability, and completes the requirement for technical documentation stated in Table D-2 of ER 13749P.

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SUMMARY

A summary of the technical documentation, as outlined in Table D-2 of the Reliability Program included in ER 13749P, is presented in this report. The latest reliability apportionment, prediction, and assessment models have been made a part of this report. Also, the results of the failure mode and criticality analysis, and a summary of the Head to Head Test failures and corrective action are contained in this report. The required reliability documents that have been published elsewhere are noted and identified.

The failure rate analysis based on generic failure rates indicate that the Support Equipment will have an operational MTBF of 877 hours for the complete system. The critical components have a combined MTBF of 1270 hours. The critical components are defined here as components whose failure can cause a test stoppage. These two MTBF values exceed the minimum reliability design goals of 600 hours and 1000 hours respectively stated in the design criteria.

The mechanical components of the hydraulic and pneumatic systems dominate the critical failure rates. The critical failure modes are distributed throughout the system as shown in Table I and there are no outstanding points of unreliability. No design changes are dictated by this failure mode and criticality analysis. However, during the preliminary design (Phase I, Contract NAS 8-11661) a failure mode analysis was made resulting in a number of design changes which significantly improved the MTBF.

Failure data and corrective action for the Head to Head Test is summarized in Table II. This data is not considered significant enough to warrant the establishment of an assessment model. First, the failures occurred on the head to head configuration rather than the operational configuration. Second, numerous failures can be expected during the development testing of any newly designed system. In addition, the test failures observed included components found by failure analysis to be bad at installation. Third, while the test

operating time was approximately 500 hours, much of the operational configuration was not used during the entire test period. Also, a number of development changes were made during the test period.

I. INTRODUCTION

Due to the nature of this program and the purpose for which the Hydrodynamic Support Equipment is to be used, the equipment has been designed around commercially proven components. Full scale component development test programs, usually required for flight vehicle and launch equipment, are not appropriate for this program. Instead the component test program consisted of functional tests and development tests for parts used in new applications. Therefore, the reliability analysis has been based on generic failure rates rather than specific component test results.

The Support Equipment Reliability Program is described in Appendix D of ER 13749P with the applicable paragraphs of NCP 250-1 noted. The technical documentation listed as part of the Reliability Program requirement is included as referenced in this report.

II. RELIABILITY DOCUMENTATION

Engineering Report 13749P lists 11 areas of reliability concern that require Engineering documentation in accordance with applicable paragraphs of NCP 250-1. This section is intended to reference the documentation of these areas or to fulfill the requirement for the areas not documented elsewhere.

A. Reliability Program Plan

The Hydrodynamic Support Equipment for Saturn V Reliability Program Plan, dated March 12, 1965, was submitted to the customer for approval on 19 March 1965. The Program Plan outlines the reliability tasks to be accomplished on this program. These tasks cover the 11 areas of this section. Additional items include requirements for a unified data file and a reliability training program. The reliability training program consisted of a series of technical discussions between the reliability engineer and the designers as required. A series of meetings were also held with quality control and manufacturing personnel to acquaint them with potential problems that would affect the reliability of areas in which they had responsibility.

B. Design Review Reports

Four formal design reviews were held at the Martin Company and several informal reviews were held at MSFC during the design and test period of this program.

The first design review is documented in the minutes of the meeting dated 16 March 1965. The problem of instability at maximum load and soft spring rate, and several contract interpretations were the major items for discussion. The Martin solution to the instability problem was to be applied after some modifications to the solution were made. Questions concerning the contract were clarified later by correspondence.

Minutes of the second design review held on 28, 29 April 1965, have been included in the Engineering Progress Report #3 for April 5 to 30, 1965. Major items of this meeting were the review of the stability problem solution, head to head test specifications, and proposed changes to Exhibit "A" of the contract. The submittal data was scheduled for the final report covering the Martin dynamic analysis. Five changes to the Head to Head Test Specification were agreed upon and the submittal date was established for the test specification.

The third review was held on 3 August 1965. The program status was presented and the Float Sunk System was discussed. No specific conclusions were reached at this meeting that affected the design or program status.

On 31 August 1965 a review of the Head to Head Test results was held. Agreement was reached to replace the first pair of cylinders with the second pair for the remainder of the tests. Several additional investigations were to be made during the next series of tests to obtain more vertical damping data. This meeting is reported in the Engineering Program Report No. 7 for August 1 to August 31, 1965.

C. Design Specifications

Paragraph 3.2 of NCP 250-1 applies only to the Design Criteria, 88A100401, for this program since the support equipment components are purchased to the vendor commercial specifications. Parts and components requirements for quality and performance included in the Design Criteria meet the intent of Section 3, Parts and Materials Programs, of the Reliability Program Plan. The program reliability goals are also documented in the Design Criteria.

The Design Criteria was made a part of ER 13749P and submitted with the proposal. It has since been updated periodically. The Design Criteria, 88A100401, Revision "D" was submitted to the customer for approval under Martin letter MB-1312 dated 14 July 1965.

Forty-two specification drawings were created for purchased components. These are listed on Table I. The drawings call for commercially proven shelf items to meet the particular applications for the equipment. Where the commercial specifications of the part met the equipment specification, no special tests were required. Development tests were conducted to verify necessary modifications to some components. These tests are included in the Development Test Report (see Paragraph K). All critical components were functionally tested during the Head to Head Test.

D. Test Specifications and Procedures

The tests specified in the Design Criteria consist of development tests, production tests, and post installation tests. These tests are intended to demonstrate or verify the functional design requirements. The test specifications and procedures meet Paragraph 4.3.3 of NPC 250-1 in general as applicable to the type of testing intended.

The Hydraulic Power Unit Test Specification, 88A4100870, and the Head to Head Test Specification, 88A4100403, along with the Head to Head Test Procedure, SK88A4100403, outline the requirements and procedures for most of the development and production tests. Post-installation functional test procedures are covered in Post Installation Procedure, 88A4100855. Other nonfunctional tests are specified on the applicable installation drawings.

In accordance with Paragraph VI of Exhibit "A", two documents were submitted to MSFC for approval and constitute the acceptance test

TABLE I - Specification Drawings

Accumulator - Hydraulic	88A4100825
Heat Exchanger, Oil/Water	" 826
Pump, Hydraulic, Fixed Volume	" 827
Pump, Hydraulic, Variable Volume	" 828
Valve, Flow Control	" 829
Valve, Ball 4", Hydraulic Shut-off	" 830
Filter, Hydraulic	" 831
Gage, Pressure, Hydraulic	" 832
Gage, Pressure, Hydraulic	" 833
Valve, 2" ShutOoff	" 834
Valve, Unloading	" 835
Valve, Check, High Pressure	" 836
Valve, Header, Shut-off	" 837
Pump, Booster	" 838
Valve, Check-Cutridge	" 839
Valve, Shut-off, GN_2	" 840
Sight Glass	" 841
Relief Valve, Hudraulic	" 842
Relief Valve, GN_2	" 843
Valve, Check Hydraulic	" 844
Accumulator - Five(5) Gallon	" 845
Reservoir, Unpressurized	" 846
Temperature Indicator	" 847
Valve, Director	" 848
Valve, Flow Control, Variable	" 849
Regulator, GN_2	" 850
Regulator, Hand Loader, GN_2	88A4100851

TABLE I (continued)

Differential Pressure Indicating System	88A4100875
Sixteen Point Recorder and Transducer	" 876
Reservoir Oil Heating System	" 877
Motors and Starters, 200 H.P.	" 878
Distribution Control Center	" 879
Pressure Switch System	" 880
Cylinder Heating System	" 882
Voltage Regulating Transformer	" 883
Rectilinear Dual Potentiometers	" 884
Resistance Bridge Indicator	" 885
Oil Level Sensing System	" 887
Oil Return Line Heating System	" 889
Oil Temperature Control System	" 890
Limit Switches	" 892
Control Panel Indicators and Switch Operators	88A4100893

procedures required for demonstration of the contract requirements. The Head to Head Test Specification was submitted to MSFC by Martin letter dated 13 May 1965 and the Post Installation Test Procedure was submitted to MSFC for approval on 8 October 1965 for Part I and on 20 October 1965 for Part II.

E. Reliability Block Diagram

For the purpose of analyzing the reliability of the Hydrodynamic Support Equipment, the system components have been arbitrarily divided into fifteen subsystems. These subsystems together with their apportioned failure rate goals are shown in Fig. 1.

Two failure rates are listed for each subsystem. The sum of the failure rates in line "A" will give the equipment a MTBF of 600 hours and the sum of line "B" will give the system a MTBF of 1000 hours. The failure rates in line "A" are the apportioned goals for all of the components in each subsystem. The failure rates in line "B" are the apportioned goals for those components in each subsystem whose failure could cause a shutdown during a test.

The goal for each subsystem was apportioned by the equal risk method modified to account for the number and complexity of mechanical components in each subsystem.

F. Reliability Prediction Model

The subsystems established for the reliability diagram in Fig. 1 have been analyzed and generic failure rates assigned to their components. The prediction model for the equipment is shown in Fig. 2. The failure rates in line "C" are the summations of the failure rates of each component in the particular subsystem. These numbers do not take redundancy into

	Electrical Power Supply	Hydraulic Power	Hydraulic Control	Nitrogen Supply	Oil Temp. Control
Line "A"	.0000500	.0002000	.0005000	.0003000	.0001000
Line "B"	.0000500	.0001000	.0002750	.0002250	.0001000

	Pump Motor Control	Boost Pressure Control	Remote Oil Flow Control	Raise-Park Control	Piston Height Indication
Line "A"	.0000500	.0000500	.0000500	.0000500	.0000500
Line "B"	.0000250	.0000500	.0000250	.0000250	.0000250

	Float Height Indication	Contact Warning	Float Sunk	Cylinder Purge	Structure → $\Sigma\lambda$
Line "A"	.0000500	.0000500	.0000500	.0000500	.0000500
Line "B"	.0000500	.0000250	.0000250	--	--

Σ Line "A" = λ_s = .0016500, $1/\lambda_s$ = 600 hr. MTBF = System Goal

Σ Line "B" = λ_c = .0010000, $1/\lambda_c$ = 1000 hr. MTBF - Criticality Goal

Fig. 1. RELIABILITY BLOCK DIAGRAM

	Electrical Power Supply	Hydraulic Power	Hydraulic Control	Nitrogen Supply	Oil Temp. Control
Line "C"	.0000258	.0001969	.0010012	.0002817	.0001124
Line "D"	.0000258	.0001313	.0003456	.0002692	.0001124
Line "E"	.0000178	.0000802	.0002534	.0001913	.0001123

	Pump Motor Control	Boost Pressure Control	Remote Oil Flow Control	Raise-Park Control	Piston Height Indication
Line "C"	.0000077	.0000509	.0000155	.0000146	.0000175
Line "D"	.0000077	.0000509	.0000155	.0000138	.0000175
Line "E"	.0000069	.0000472	.0000155	.0000138	.0000175

	Float Height Indication	Contact Warning	Float Sunk	Cylinder Purge	Structure $\rightarrow \Sigma\lambda$
Line "C"	.0000571	.0000174	.0000291	.0000453	.0000010 (Assume)
Line "D"	.0000571	.0000174	.0000291	.0000453	.0000010 (Assume)
Line "E"	--	.0000174	.0000173	--	--

Σ Line "C" = λ_m = .0018741, $1/\lambda_m$ = 435 hr. MTBF = Maintenance Production

Σ Line "D" = λ_s = .0011396, $1/\lambda_s$ = 877 hr. MTBF = System Prediction

Σ Line "E" = λ_c = .0007866, $1/\lambda_c$ = 1270 Hr. MTBF = Criticality Prediction

Fig. 2. RELIABILITY PREDICTION MODEL

account and can be used as a basis for planning maintenance schedules. Line "D" failure rates include the effects of redundancy and the inverse of the summation of these numbers is the predicted MTBF for the support equipment. Line "E" failure rates include failure rates of only those components whose failure could cause a shutdown during a test.

The failure rate analysis used for this prediction model is based on component generic failure rates contained in the Martin Reliability Policy and Procedures Manual, M-63-3. The following assumptions are used in the calculations:

(1) Only single failures are considered

(2) Cyclic components cycle once per hour

(3) Components manufactured to commercial standards have the same failure rate as like components manufactured to military specifications.

(4) Failure rates of structure designed to conventional stress levels and safety factors have no significant effect on this analysis.

(5) The operating and application factors are not considered in the prediction model.

Redundant critical components were used 21 places in the equipment. Table II lists these components and compares the quantity required for the system operation and the total generic failure rates with the quantity installed in the system and the improved failure rates resulting from the redundancy. The addition of the redundant components has increased the predicted MTBF for the critical components from 755 hours to 1270 hours.

The binomial distribution was used to calculate the failure rate for each redundant group of components. The calculations were simplified due to each of the parallel components having the same failure rate.

Table II - Redundant Components

Component	Qty. Reqd.	$GF_p \times 10^6$	Qty Used	Redundant $GF_r \times 10^6$
Support No. 1				
Flow Control Valve FCV 13, 14, 15, 19, 20, 21	5	32.5	6	.000634
Flow Control Valve FCV 16, 17, 18, 22, 23, 24	5	32.5	6	.000634
Flow Control Valve & check valve in series FCV-25, CHV-2 & CHV-3	1	11.5	2	.000132
Flow Control Valve & check valve in series FCV-33, CHV-4 & FCV-34, CHV-5	1	11.5	2	.000132
Flow Control Valve FCV-27, 28, 29, 30, 31, 32	5	32.5	6	.000634
Support No. 1 Totals		120.5		.002166
Support No. 2 Totals *		120.5		.002166
Support No. 3 Totals *		120.5		.002166
Support No. 4 Totals *		120.5		.002166
Accumulator (20 gal) ACC-2 through ACC-10	8	57.4	9	.001766
Total		439.4		.010430

* Supports Nos. 1, 2, 3 & 4 have identical components.

Elimination of the redundant components will reduce the reliability of the critical components by increasing the sum of their failure rates by .0004394 -.00000001. From Fig. 2 λ_c would equal .0007866 + .0005394 or .001326.

Expansion of the binomial distribution for success based on allowing one or less failures is:

$R_R = R^n + n\ R^{n-1}Q$ = the reliability of a redundant system of n like components in parallel and one or less failure equal success.

$R + Q = 1$ = the reliability plus the unreliability of a single component.

$Q_R = 1 - \ (R^n + nR^{n-1}Q)$

$= 1 - \ (1-Q)^n + nQ\ (1-Q)^{n-1}$ = the unreliability of a redundant system of n like components in parallel and two or more failures equal system failure.

For small values of $Q < .001$, $Q = \lambda t$

Assuming $t = 1$ hour $Q = \lambda$

$Q_R = 1 - \left[(1-\lambda)^n + n\,\lambda\ (1-\lambda)^{n-1}\right]$ = the failure rate of the redundant system of n like components in parallel and two or more failures equal the redundant system failure.

Substituting the equivalent failure rate, $_R$, for the failure rates of the redundant components of each subsystem, each subsystem can be analyzed as a series system where:

$S = \sum_{e=1}^{i=n} \lambda\ i$ = the subsystem failure rate for n components in series with λi equal the failure rate of each component.

The predicted MTBF's shown in Fig. 2 meet the goals shown in Fig. 1. The predicted maintenance MTBF of 534 hours is less than the goal of 600 hours for the entire system, but the use of redundant components raises the predicted system operational MTBF to 877 hours. The predicted MTBF of 1270 hours, for those components which could cause a test shutdown, meets the design goal of 1000 hours MTBF for these components.

It should be noted that the predicted MTBF is based on the equipment being properly installed, operated and maintained. Proper maintenance includes preventive maintenance such as lubrication, cleaning, adjustment, and alignment, as well as replacing components nearing wear-out condition. Abusive treatment of components during installation and operation or poorly maintained components can seriously degrade the system.

System degradation due to contamination problems must be minimized by good housekeeping and general cleanliness practices. Potential hydraulic oil contamination can be minimized by cleaning the areas around the bearing oil return shrouds, filters, and reservoir filler, particularly before opening these units.

G. <u>Failure Mode Effect and Critical Analysis</u>

Each subsystem of the Hydrodynamic Support Equipment shown in Fig. 1 has been analyzed for critical components which will affect the equipment reliability. The analysis is based on the following definitions and assumptions:

(1) A critical component is any component whose failure will require the shutdown of the equipment during testing.

(2) Only single component failures are considered for the critical analysis except as noted in item (3) below.

(3) Where redundancy of components occurs in the equipment, the redundant items failure rates are combined, using the binominal distribution. The combined failure rates are assumed to represent a single component in the subsystem.

TABLE III

CRITICAL COMPONENT FAILURE MODE SUMMARY

Note: Components are grouped by subsystems.

TABLE III-a Sub-System-Electrical Power Supply

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Motor Starter 88A4100879	2 (MS-2&3)	2.25	Contacts fail open.	Loss of pump motor resulting in an insufficient oil flow to cylinders or bearings. Would require a system shutdown.
Motor Starter 88A4100879	1 (MS-1)	2.00	Contacts fail open.	Loss of boost pump motor and boost pressure which will shut down the system.
Transformer 110 vac Dist.	1 (T-14)	1.04	Short or open circuit	Loss of 110V circuits will remove power from pump motors and shutdown system.
Transformer 24 vac Dist.	1 (T-15)	1.04	Short or open circuit.	Loss of 24V circuit will stop pump motors and shut down the system.
Motor Starter Interlock Relay	3 (CR13-15)	.25	Contact fails open	Motor power drops out when start button is released. Hydraulic pump will not continue to run.

TABLE IIIb Sub-System - Hydraulic Power

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Reservoir 88A4100846-001	1 (R-1)	1.41	Burst	Loss of hydraulic oil to pumps and system will shut down.
Booster Pump 88A4100838-001	1 (P-1)	13.60	Frozen impeller	Loss of oil flow which will shut down system.
Filter 88A4100831-001	2 (F-9, 10)	2.13	Cartridge rupture	Contamination released into system which could damage pumps or bearings.
Pump, Constant Pressure 88A4100828-002	1 (P-2)	13.60	Loss of pressure, Frozen pump	Insufficient pressure to support piston would require system shutdown.
Pump, Constant Volume 88A4100828-001	1 (P-3)	13.60	Loss of pressure, frozen pump	Insufficient flow to bearings would require system shutdown.
Check Valve 88A4100836-001	3 (CHV-1, 6, 7)	6.10	Fail to open	Prevent oil flow from pump to cylinder or to bearings and accumulators.
Relief Valve 88A4100835-001	1 (RV-6)	4.20	Relieves below sys. operating pressure	Degrade operation of piston and bearings and require shut down of test.
Control Valve 88A4100840-002	1 (CV-27)	6.10	Fail to close	Relief valve RV-6 will remain open below the system operating pressure. Required pressure will not reach the cylinders.
Control Valve 88A4100840-001	1 (CV-35)	6.5	Fails open	Boost pressure will not reach the main pumps and system operating pressure or flow may not be achieved.

TABLE IIIc Sub-System Hydraulic Control

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Filter 60HP25D-M-20-YY-3	8 (F1-8)	.3	Element ruptures	Contamination released to control valves and bearings. May block a line or score a critical surface.
Pressure Regulator Valve 88A4100850-001	4 (PRV1-4)	8.5	Fails open	Affected piston travel will exceed other pistons.
			Fails closed	Affected piston will remain in park position.
Flow Control Valve 88A4100449-001	4 (FCV1-4)	6.5	Compensator sticks open	Affected piston travel will exceed other pistons.
			Compensator sticks closed	Affected piston will remain in park position.
Flow Control Valve 88A4100449-002	4 (FCV5-8)	6.5	Fails closed	Affected piston travel will exceed other pistons.
			Fails open	Affected piston will remain in park position.
Relief Valve 88A4100842-001	4 (RV1-4)	5.7	Relieves below system operating pressure	Affected piston will remain in park position.
Cylinder 88A4100410	4 (CV1-4)	5.1	Float sinks	Float acts as check valve at lower seal preventing action of air spring.
			Float sticks	Air spring lost due to frozen float.
			Piston binds on cylinder	Friction degrades dynamic characteristics of system.
Bearing Assy. 88A4100405	4 (BRG1-4)	1.0	Metal bearing surface contact	Excessive friction can absorb shaker side loads.
Remote Operated Valve QJ-10-C-V-10A1	4 (ROV1-4)	11.0	Fail closed	Piston cannot be raised from park position.
			Fail open	Piston cannot be lowered.
Lines & Fittings	160 (estimated)	0.2	Rupture	Loss of hydraulic oil to pistons or bearings Pressure loss will cause shutdown
Pressure Hoses	4	3.94	Rupture	Loss of hydraulic oil to bearing. Bearing surface will not be lubricated.

TABLE IIId Sub-System Nitrogen Supply

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Control Valve 88A4100840-004	1 (CV-25)	6.5	Fail closed	No nitrogen supplied to system
Loader Valve LV-10-54A-4A3	1 (PRV-5)	8.5	Fail open Fail closed	System receives an overcharge of N_2 No N_2 supplied to system
Pressure Regulator Valve 88A4100850-001	1 PRV-6	8.5	Fail open Fail closed	System receives an overcharge of N_2 No N_2 supplied to the system
Loader Valve LV-10-54A-4A3	1 PRV-7	8.5	Fail open Fail closed	Piston supply regulator valves will be driven full open, causing pistons to rise. Piston supply regulator valves will not open and pistons cannot be raised.
Relief Valve 88A4100843-001	1 RV-5	5.7	Relieves below sys. operating pressure	Loss of pressure to N_2 operated regulator valves and piston air springs.
Control Valve 88A4100840-002	4 CV-5-8	6.5	Fail open Fail closed	Piston receives over charge, float is bottomed. Piston cannot be charged, no air spring control.
Control Valve 88A4100840-001	4 CV9-12	6.5	Fail open Fail closed	Piston cannot be charged. Piston cannot be discharged.
Liquid Level Indicator 88A4100841-001	4 LLI-1,4	3.13	Sight gage glass breaks	Gradual loss of piston charge. Pneumatic spring rate cannot be maintained.
Liquid Level Indicator 88A4100841-002	4 LLI-5-8	3.13	Sight gage glass breaks	Gradual loss of piston charge. Pneumatic spring rate cannot be maintained.
Lines and Fittings	100 (estimate)	0.2	Rupture	Loss N_2 supply to valves or pistons System cannot be regulated.
Pressure Hoses	8	3.94	Rupture	Loss of N_2 supply to pistons. Piston air spring will be lost.

TABLE IIIe Sub-System Oil Temperature Control

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Heat Exchanger 88A4100826-001	1 HE-1	12.9	Burst	Loss of oil and/or cooling water. System shutdown or oil may overheat.
Temperature Controller 88A4100890-004	1 TC-1	75.0 (estimated)	Transmitter fails Controller fails	No cooling water flow to heat exchanger Cooling water valve is full open - may prevent oil from reaching operating temp.
Temp. Control Valve 88A4100890-003	1 TCV-1	6.5	Fail closed Fail open	No cooling water flow to heat exchanger May prevent oil from reaching operating temp.

TABLE IIIf Sub-System Motor Control

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Motor, Boost Pump	1 M-1	.625	Internal short or break, or frozen bearing	Loss of boost pump. System will shut down.
Motor, 200HP 88A4100878	2 M-2,3	.625	Internal short or break, or frozen bearing	Loss of c.v. pump or c.p. pump, no hydraulic pressure to cylinders.
Transformer 117/24 vac	1 T-1	1.04	Short or open circuit	Loss of elect. power to boost pump motor control. Motor will shut down.
Switch & Relay Contacts	19/cs	.25/cs	Fail open	Loss of current to pump motors. System will shut down.

TABLE IIIg Sub-System Boost Pressure Control

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Pressure Controller See 416OR-657A	1 PC-1	27.0 (estimated)	Internal leak or valve failed closed.	Under control of regulator allowing excessive boost-pressure build up.
			Internal valve fails open.	Open press. regulator and unload boost press.
Remote Operated Valve 88A4100848	1 ROV-5	11.0	Fail closed	Regulator valve will not open to relieve high boost pressures.
			Fail open	Regulator valve will unload boost press.
Pressure Regulator Valve 416OR-657A	1 PRV-8	8.5	Fail closed	High boost pressure cannot be unloaded.
			Fail open	Boost pressure will not build up.

TABLE IIIh Sub-System Oil Flow Remote Control

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Pushbutton Switch	8 CS	.25/CS	Contacts fail in valve close position Contacts fail in valve open position	Flow control valve closes & affected piston travel will exceed the other pistons. Flow control valve opens & affected piston will remain in park position.
Transformer 88A4100887	4 T18-21	1.04	Short or open circuit	Loss of power to control valve motor-oil flow to piston cannot be controlled.
Motor, Valve Control 88A4100897	4 M4-7	.3	Internal short or frozen bearing	Loss of control valve adjustment-oil flow to piston cannot be controlled.
Motor Control Potentiometer 88A4100897	4 P1-1-4	1.375	Faulty reading	Motor controlled valve position cannot be determined

TABLE IIIi Sub-System Raise-Park Control

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Pilot Relay	1 CR-12	.50	Contacts fail open	N_2 supply valve for operating the piston oil supply valves will remain closed.
			Contacts fail closed	N_2 supply valve will not close - Pistons cannot be lowered without shutting down.
Remote Oper. Valve	1 ROV-10	8.50	Fail closed	Piston oil supply valves will not open - Pistons cannot be raised
ASCO-83444			Fail open	Piston oil supply valves will not close- Pistons cannot be lowered without reducing nitrogen pressure. (PRV-9)

TABLE IIIj Sub-System Piston Height Indicating

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Linear Potentiometer	4 LPI-4	3.0	Circuit short Circuit break	Faulty piston height indication No piston height indication, proper piston height cannot be verified.
Resistance Bridge Indicator 88A4100885-001	4 IND1-4	1.375	Meter failure	No piston height indication, proper piston height cannot be verified.

TABLE IIIk Sub-System Float Height Indication

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
No critical components - system redundant with the liquid level indicators.				

TABLE IIII Sub-System Contact Warning

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Pushbutton Switch 88A4100898-299	1	.113	Fail Open	Loss of warning system
Contact Power Relay 2PNO/110	1	.50	Fail Open	Loss of warning system
Transformer 107/6 VAC	12	1.04	Burn out	Loss of warning indicator
Resistors	36	.04	Broken circuit	Loss of warning indicator
Pushbutton Switches 88A4100893-109 -119 -129	12	.113	Fail open Fail closed	Loss of warning indicator False warning indication

TABLE IIIm Sub-System Float Sunk Indication

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
Sensor	4	2.60	False cover signal	False indication of sunken float would cause unnecessary test stop.
Transistor	8	.61	Short	Energize indicator relay giving a false sunk indication.
Relay	4	.50	"Sunk" contacts fail closed.	Give false indication of sunken float.

TABLE IIIn Sub-System Cylinder Purge

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test
No critical components - system not operated during test.				

TABLE IIIo Sub-System Structure

Component Name and P/N	Qty. Used	Basic Failure Rate x 10^6	Failure Mode	Effect of Failure on Test

No critical components - structure designed to conventional stress levels and safety factors; failure rates are not considered significant in this analysis.

(4) All components are assumed to be good at the start of the test.

(5) Components not operated during the test are assumed to have no critical failure mode.

Table III contains the list of critical components in each subsystem which are major contributors to the proabability of stopping a test. The table includes the component, the quantity used, the generic failure rate, the failure modes which are critical, and the effect of the failure on the equipment during the test.

The sum of the critical components failure rates for each subsystem is shown on the Prediction Model (Fig. 2). Items contributing less than one per cent of the subsystem critical failure rate are not included in Table III. The redundant component combined failure rates were found to have no significant effect on any of the subsystem critical failure rates.

H. Failure and Corrective Action Summaries

Table IV is a summary of component failures and the corrective action taken during the Head to Head Test Program. The 18 failures can be groups into 3 general categories. Nine failures were due to using components that were not suitable for the application. These are the type failures anticipated during the development phase when components are not specifically designed for a given application. Failure analysis of six failures indicates that they were due to faulty components. These parts were not properly inspected, debugged, or calibrated prior to being used in the test. The causes of the 3 remaining failures are unknown.

Of the three unknown failure causes two were corrected by replacing the failed parts, one with an identical part and the other with a similar part obtained from a new source. The third unknown cause of failure in which the piston float was found to be out of round, was dropped inadvertently. The float has been remachined and rechecked and is now installed in the spare piston.

I. Human Factors and Maintainability

Mil-Std-803A-1 (USAF) entitled "Human Engineering Design Criteria for Aerospace Systems and Equipment" was used as a guide for design and fabrication of the Saturn V. Hydrodynamic Test Stand. Care was taken to arrange the equipment for the most efficient use by a minimum number of operating and maintenance personnel consistent with functional requirements and practical design.

The operator's control console is centrally located to all equipment and enclosed in a small building. The control panel is located on the console and is divided into two halves. The left-hand half contains those controls and readouts necessary to supply and regulate electrical, hydraulic, and pneumatic power or supply to the test stand.

The right-hand of the panel contains those controls and readouts necessary to monitor and control the operation of the test stand during tests. The right-hand panel is horizontally divided into four sub-panels. The sub-panels each contain a laterally arranged display of all monitored functions of a particular pedestal and are numbered one through four from top to bottom. These numbers correspond to the numbers of each of the four pedestals. This arrangement makes it possible to read and compare the value of one function for all four pedestals in one vertical scan.

All switches are of the push-button light type, such that readout and control are at the same point. The light bulb holder design within the switches is of an advanced nature such that the bulbs may be easily removed for inspection and replacement without the use of special tools.

TABLE IV - Failure and Corrective Action Summary

Component	Failure Mode	Cause of Failure	Corrective Action
Filter 60HP25D-M-20-YY-3	Filter element rupture	A high differential pressure was applied across the filter.	The standard filter element was replaced with a heavy duty element which contained a re-inforcing screen.
Piston Height Indicator	Incorrect readings	The piston movement deflected the potentiometer mounting.	The potentiometer assembly and mounting were redesigned.
Flow Control Valve 88A4100449-002 (FCV-5)	Automatic valve control will not keep valve positioned within limits.	Valve control is unsatisfactory. Hysteresis was found in valve control.	Motor automatic control has been replaced with manual control.
Boost Pump Bypass Valve (ROV-5) 88A4100848	Valve control solenoid burned out	Unknown	Valve was replaced with a similar valve from a different manufacturer.
Nitrogen Bleed Control Valve (CV-26)	Leaking valve	Poor workmanship in the manufacture of the valve.	Valve was replaced with a valve of acceptable quality.
Main Hydraulic Press. Gage (P-6) 88A4100832-003	Isolation diaphragm ruptured.	It is believed that a fluid leak developed on the gage side of the diaphragm.	Diaphragm was replaced with one which has better sealing characteristics.
Pressure Regulator Valve (PRV-7)	Regulator pressure drifted	This regulator had chronic leakage problems.	The regulator valve was replaced with a Victor Co. loader valve.
Pressure Regulator Valve (PRV-1) 88A4100850-001	Nitrogen leak in the regulator dome.	Unsymmetrical porting on valve side of diaphragm plate caused internal damage.	Symmetrical ports were added and valve was repaired.
Remote Operated Valve (ROV-1 & 2) QJ-10-C-V-10A1	Solenoid plunger stuck in the energized position.	The application exceeds the design intent of the solenoid spring.	The solenoid actuator was replaced with a pneumatic actuator.
Differential Pressure Transducer (DPT-1) 88A4100895-001	Signal to differential pressure indicator was unaffected by a pressure change.	Application of excessive differential pressure across the transducer caused internal damage.	The hydraulic circuit was changed to prevent the high differential pressure buildup and the transducer was repaired.

TABLE IV (continued)

Component	Failure Mode	Cause of Failure	Corrective Action
Pressure Gage (PI-5) 88A4100832-001	The indicating hand was sticking.	The indicating hand was rubbing on the gage glass face cover.	The hand was altered to provide sufficient clearance.
Pressure Controller PC-1 4160R-657A	Failed to open the regulator valve when the boost pressure exceeded the design pressure limit.	Pressure transmitting fluid leak between the diaphragm and the controller. Leak was due to the improper assembly of the diaphragm.	The diaphragm assembly was repaired and reassembled correctly.
Pressure Regulator Valve (PRV-5) 88A4100851	Regulator failed to close valve.	This regulator had chronic leakage problems.	The regulator valve was replaced with a Victor Co. loader valve.
Pressure Gage (PI-9) 88A4100833-003	Internal leak	Unknown	The gage was replaced and no trouble reported for the new gage.
Accumulator charging valves	Valves leak	Valves were distorted by excessive torque being applied to the valve caps.	The valves were replaced and the caps were discarded. The caps are not required for proper system operation.
Accumulator (ACC-2-10) 88A4100825-001	Internal leaking	"O" rings were not properly lubricated at installation	"O" rings and their back-up rings were replaced.
Piston Float	Float interferes with inside wall of piston.	Float was out of round. Cause of out-of-roundness is unknown.	Float was remachined to proper size.
Pump Motors Circuit Breakers	Breakers opened when motor start was attempted.	Breakers had dirty contacts (solder spill) and were set too sensitive.	Breakers were reworked and reset to a lower sensitivity.

Easy access to the inside of the console is provided by removable panels on the back side. The arrangement of the equipment within the console is such as to be easily reached without undue stooping, bending, etc. The console itself was purchased from the Emcor division of the Borg-Worner Corp. This is desirable so that all consoles used on the program are standardized and interchangeability is preserved for easy maintenance.

Since most testing is done at the minimum support spring rate, the equipment is designed such that the operator need not change the settings for any vehicle weight on any equipment other than those controls located on the control panel. Only if different spring rates are desired is it necessary to change remote equipment settings.

Throughout the test stand, components have been standardized as much as possible to provide maximum interchangeability and minimum spares. An example of this may be found in the two high pressure pumps, either of which may be used for fixed or pressure compensated flow delivery.

For ease of maintenance, all filters are located in easily accessible places and are equipped with contamination indicators. These indicators give continuous indication of the cleanliness of the filter elements such that maintenance can be carried out as required.

All components are installed using CPV (Combination Pump Valve Co.) fittings such that they are easily removable for maintenance or replacement. The CPV fitting is similar to the ordinary pipe union fitting except that an "O"-ring is used to seal the mating faces. Leaks in the fixed pipe joints have been eliminated by welding, thus making a permanent seal.

On each pedestal, access platforms and removal equipment have been provided for maintenance and repair or removal of the piston-cylinder assembly and bearings. Also provided are shoes, shims, and locks to facilitate the handling of the piston-cylinder assembly without damage.

To prevent contamination of the hydrostatic bearing area and the open scupper, the upper end of the pedestal has been completely enclosed in a housing.

J. <u>Reliability Assessment Model</u>

A test program to demonstrate the MTBF of the Hydrodynamic Support Equipment is not appropriate to the program. The requirements in the design criteria are to demonstrate the system reliability by analysis. The analysis has shown, based on generic failure rates, that the system as designed will meet the MTBF goals of the program. The probability of the system meeting this prediction will be affected by installation problems, contamination control, maintenance, and general handling of the equipment.

The failures experienced during the Head to Head Test might indicate that the MTBF is much lower than the prediction. The equipment was operated approximately 500 hours and 18 failures occurred. This amounts to a demonstrated MTBF of only 28 hours. However, the Head to Head Test results are not a true indication of the system's MTBF. This test was primarily a development type test. Failure analysis showed a number of components were faulty at installation and corrective action in the form of design changes eliminated still other failures. The experienced failures are the type expected during the development and debugging phases of any new design. For a reliability assessment the test or operating time should not include debugging tests since the assessment should reflect the reliability of components that meet and are operated within the design specifications.

A significant number of failures of flow control valves occurred during the test of the second set of cylinders and pistons when the oil became inadvertently contaminated. In order to achieve the predicted reliability it is mandatory that the system be maintained at an acceptable contamination level. In order to maintain an acceptable contamination level in the hydraulic system the area around components which are exposed during servicing must be kpt clean and free from any significant airborne dust. The most important components in this category are all filters, the reservoir manhole cover, and the flat and spherical hydrostatic bearings.

K. Test Reports

The development and production tests conducted on this program are documented in two test reports. The Air-to-Oil Interface Tests, Flow Control Valve Tests and Modifications, Hydraulic Pressure Regulator Tests and Modifications, Capillary Valve Development Tests, Float Height Indicating System, Float Sunk Detection System, and the Bearing Contact Warning Tests are included in the Development Test Report ER 14037. The Head to Head Test Report, ER 14036, covers the 11 functional tests, Vibration Surveys, and Damping and Piston Characteristics Tests that were conducted with the equipment in the head to head configuration. These reports form a portion of the final documentation submitted by the Martin Company.